5 a) The 42/14 Volt Automotive
Electrical System
CSSL-IV Program Listing

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PROGRAM ADEM
" Automotive Electrical System Model "
" Technical Consultants: "
" Ronald Krefta-(765)451-3782: synchcronous generator with 3-phase "
" delta connected stator winding and dc-excited rotor winding. "
" TV Sriram-(765)451-3821: 3-phase diode rectifier bridge circuit."
" James Moore-(765)646-2395: voltage regulator with analog controller."
" Mike Bradfield-(765)649-3049: generator mechanical details."
" Steve Cochran-(317)579-3730: lithium polymer(LiPo) battery."
" Dr. Alfred Barrett-(765)451-3830: DC-DC buck converter."
" Technical Coordinator: Dr. John McBain-(765)451-3739 "
" Program Developer: Dr. Yilmaz Sahinkaya-(650)574-0254 "
" Model Creation Date: September 7, 2000 "
                  " Units : Metric "
                  " System Parameters "
" General Parameters"
" TFIN = Simulation Time (sec) "
CONSTANT TFIN    = 100.0E-3
" Engine Speed Command Model Parameters "
CONSTANT TEACC   =    0.0            $" Engine Starting Time (sec) "
CONSTANT TERISE  =    2.0            $" Engine Speed Rise Time (sec) "
CONSTANT NEACC   =  764.0            $" Engine Speed Rise Rate (rpm/sec) "
CONSTANT TESS    =   20.0            $" Engine Speed Cruise Time (sec) "
CONSTANT TEFALL  =    5.0            $" Engine Speed Fall Time (sec) "
CONSTANT NEDEC   = -382.0            $" Engine Speed Fall Rate (rpm/sec) "
CONSTANT NEZ     =  640.0            $" Initial Engine Speed (rpm) "
CONSTANT MODCON  =    1.0            $" MODCON = 1.0, Gen Control is on"
                                     $" MODCON = 0.0, Gen Control is off"
CONSTANT MODTEST=     0.0            $" MODTEST = 0.0, Gen Test is off "
                                     $" MODTEST = 1.0, Gen Test is on  "
CONSTANT VGBTEST=    44.0            $" Gen Bus Test Voltage (Volts) "
CONSTANT IFGENZ  =    4.9            $" Gen Field Test Current (Amps) "
" 42 Volt Loads "
" Starter Motor Parameters "
" TSMON, TSMOFF = Starter Motor ON, OFF Times (Sec) "
CONSTANT TSMON   = 0.0, TSMOFF = 2.0
CONSTANT KTSM    =   0.7             $" Torque Constant (Nm/Amps) "
CONSTANT ISMAMP  =   150.0           $" Motor Current (Amps) "
CONSTANT RSM     =   0.025           $" Armature Resistance (Ohms) "
" Power Steering (PES) Motor Parameters "
" TPSON, TPSOFF = Power Steering Motor ON, OFF Times (Sec) "
CONSTANT TPSMON = 20.0E-3, TPSMOFF = 50.0E-3
CONSTANT KTPSM   =  1.0              $" Torque Constant (Nm/Amp) "
CONSTANT IPSMAMP=  30.0              $" Motor Current (Amps) "
CONSTANT RPSM    =  0.25             $" Armature Resistance (Ohms) "
CONSTANT OMGPS   =  1.50             $" Steering Frquency (Rad/Sec) "
" Generator Parameters "
CONSTANT VGBREF  =   42.0            $" Generator Bus Reference(Volts)"
CONSTANT GRGEN   =    2.5            $" Generator Gear Ratio "
CONSTANT NPPGEN  =    6.0            $" Number of Pole Pairs "
" LST = Synchronous Inductance(Henry) vs Generator Speed (rpm) Table "
TABLE LST, 1, 12,...
     0.0, 1600.0, 1800.0, 2000.0, 2500.0, 3000.0,...
     3500.0, 4000.0, 5000.0, 6500.0, 8000.0, 10000.0,...
     1.77E-3, 1.77E-3, 1.846E-3, 1.924E-3, 2.135E-3, 2.275E-3,...
     2.37E-3, 2.43E-3, 2.49E-3, 2.52E-3, 2.53E-3, 2.53E-3
" Stator Phase Resistances at 25 deg C (Ohms)"
CONSTANT RAGENO = 0.29, RBGENO = 0.29, RCGENO = 0.29
" ALPHAW  = Winding Resistance Thermal Coefficient /deg C Rise "
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Figure 8. The CSSL-IV Program for the 42/14 Volt Dual-Voltage Automotive Electrical System

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PROGRAM ADEM
" Automotive Electrical System Model "
" Technical Consultants: "
" Ronald Krefta-(765)451-3782: synchcronous generator with 3-phase "
" delta connected stator winding and dc-excited rotor winding. "
" TV Sriram-(765)451-3821: 3-phase diode rectifier bridge circuit."
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" Program Developer: Dr. Yilmaz Sahinkaya-(650)574-0254 "
" Model Creation Date: September 7, 2000 "
                  " Units : Metric "
                  " System Parameters "
" General Parameters"
" TFIN = Simulation Time (sec) "
CONSTANT TFIN    = 100.0E-3
" Engine Speed Command Model Parameters "
CONSTANT TEACC   =    0.0            $" Engine Starting Time (sec) "
CONSTANT TERISE  =    2.0            $" Engine Speed Rise Time (sec) "
CONSTANT NEACC   =  764.0            $" Engine Speed Rise Rate (rpm/sec) "
CONSTANT TESS    =   20.0            $" Engine Speed Cruise Time (sec) "
CONSTANT TEFALL  =    5.0            $" Engine Speed Fall Time (sec) "
CONSTANT NEDEC   = -382.0            $" Engine Speed Fall Rate (rpm/sec) "
CONSTANT NEZ     =  640.0            $" Initial Engine Speed (rpm) "
CONSTANT MODCON  =    1.0            $" MODCON = 1.0, Gen Control is on"
                                     $" MODCON = 0.0, Gen Control is off"
CONSTANT MODTEST=     0.0            $" MODTEST = 0.0, Gen Test is off "
                                     $" MODTEST = 1.0, Gen Test is on  "
CONSTANT VGBTEST=    44.0            $" Gen Bus Test Voltage (Volts) "
CONSTANT IFGENZ  =    4.9            $" Gen Field Test Current (Amps) "
" 42 Volt Loads "
" Starter Motor Parameters "
" TSMON, TSMOFF = Starter Motor ON, OFF Times (Sec) "
CONSTANT TSMON   = 0.0, TSMOFF = 2.0
CONSTANT KTSM    =    0.7            $" Torque Constant (Nm/Amps) "
CONSTANT ISMAMP  =  150.0            $" Motor Current (Amps) "
CONSTANT RSM     =    0.025          $" Armature Resistance (Ohms) "
" Power Steering (PES) Motor Parameters "
" TPSON, TPSOFF = Power Steering Motor ON, OFF Times (Sec) "
CONSTANT TPSMON = 20.0E-3, TPSMOFF = 50.0E-3
CONSTANT KTPSM   =  1.0              $" Torque Constant (Nm/Amp) "
CONSTANT IPSMAMP=  30.0              $" Motor Current (Amps) "
CONSTANT RPSM    =  0.25             $" Armature Resistance (Ohms) "
CONSTANT OMGPS   =  1.50             $" Steering Frquency (Rad/Sec) "
" Generator Parameters "
CONSTANT VGBREF  =   42.0            $" Generator Bus Reference(Volts)"
CONSTANT GRGEN   =    2.5            $" Generator Gear Ratio "
CONSTANT NPPGEN  =    6.0            $" Number of Pole Pairs "
" LST = Synchronous Inductance(Henry) vs Generator Speed (rpm) Table "
TABLE LST, 1, 12,...
     0.0, 1600.0, 1800.0, 2000.0, 2500.0, 3000.0,...
     3500.0, 4000.0, 5000.0, 6500.0, 8000.0, 10000.0,...
     1.77E-3, 1.77E-3, 1.846E-3, 1.924E-3, 2.135E-3, 2.275E-3,...
     2.37E-3, 2.43E-3, 2.49E-3, 2.52E-3, 2.53E-3, 2.53E-3
" Stator Phase Resistances at 25 deg C (Ohms)"
CONSTANT RAGENO = 0.29, RBGENO = 0.29, RCGENO = 0.29
" ALPHAW  = Winding Resistance Thermal Coefficient /deg C Rise "
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Figure 8. The CSSL-IV Program for the 42/14 Volt Dual-Voltage

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CONSTANT ALPHAW = 0.00394          $" Ohms Per Deg C Temp Rise "
" LMFT = Stator Phase-Rotor Field Mutual Inductance Table Function "
" First Independent Variable = Stator Phase Current(Amps)"
" Second Independent Variable = Rotor Field Current (Amps)"
" Dependent Variable = Mutual Field-Phase Inductance (Henry) "
TABLE LMFT, 2, 6, 12,...
     0.0, 0.1, 2.0, 4.9, 6.0, 7.0,...
     0.0, 1600.0, 1800.0, 2000.0, 2500.0, 3000.0, 3500.0,...
     4000.0, 5000.0, 6500.0, 8000.0, 10000.0,...
     0.0205, 0.0205, 0.0202, 0.0110, 0.0092, 0.0092,...
     0.0205, 0.0205, 0.0202, 0.0110, 0.0092, 0.0092,...
     0.0227, 0.0227, 0.0224, 0.0122, 0.0102, 0.0102,...
     0.0242, 0.0242, 0.0239, 0.0130, 0.0108, 0.0108,...
     0.0277, 0.0277, 0.0274, 0.0149, 0.0124, 0.0124,...
     0.0301, 0.0301, 0.0298, 0.0162, 0.0135, 0.0135,...
     0.0318, 0.0318, 0.0314, 0.0171, 0.0142, 0.0142,...
     0.0329, 0.0329, 0.0325, 0.0177, 0.0147, 0.0147,...
     0.0338, 0.0338, 0.0334, 0.0182, 0.0151, 0.0151,...
     0.0344, 0.0344, 0.0339, 0.0185, 0.0153, 0.0153,...
     0.0345, 0.0345, 0.0341, 0.0186, 0.0154, 0.0154,...
     0.0345, 0.0345, 0.0341, 0.0186, 0.0154, 0.0154

" LFGEN  = Field Self Inductance (Henry) "
" Note: LFGEN is a nonlinear function of IFGEN(Field Current(Amps))"
TABLE LFGENT, 1, 11,...
     0.0, 0.1, 0.5, 1.0, 2.0, 3.0, 4.0, 4.9, 5.0, 6.0, 7.0,...
     0.87, 0.87, 0.98, 1.0, 0.92, 0.76, 0.625, 0.54, 0.53, 0.46, 0.46
" RFGENO  = Field Resistance (Ohms) "
CONSTANT RFGENO  = 2.055            $" Ohms at 25 deg C "
" TIGREF  = Generator Interior Reference Temp ( deg C) "
CONSTANT TIGREF  = 25.0          $" deg C "
" Voltage Regulator Parameters "
CONSTANT VSREG  = 12.0           $" Regulator Supply Voltage(Volts) "
CONSTANT VBRDROP = 1.5  $" Brush and Regulator Circuit Voltage Drop(V
" Regulator PWM Parameters "
CONSTANT AMPSAW  = 0.1           $" Sawtooth Amplitude(Volt) "
CONSTANT VREFDC  = 13.50         $" Reference Voltage DC Level(Volt) "
CONSTANT SAWPER  = 0.020         $" Sawtooth Period (Sec) "
" Sawtooth Waveform Generation "
" SAWTT = Regulator Normalized Sawtooth Table "
TABLE SAWTT, 1, 9,...
0.0, 0.0045, 0.0050, 0.0055, 0.010, 0.0145, 0.0150, 0.0155, 0.020,...
0.0, 0.98, 1.0, 0.98, 0.0, -0.98, -1.0, -0.98, 0.0
" VDFWT = Free Wheeling Diode Forward Voltage Drop Table "
TABLE VDFWT, 1, 7,...
-0.1, 0.0, 1.0, 2.0, 4.0, 6.0, 8.0,...
 0.0, 0.0, 0.85, 0.90, 0.92, 0.95, 0.95
CONSTANT VGBCONZ=  0.0
" Initial Conditions on State Variables "
CONSTANT IAGENZ = 0.0, IBGENZ = 0.0, ICGENZ = 0.0
CONSTANT TAUDEC = 6.6E-6            $" Current Decay Time (Sec) "
CONSTANT TAUDIF = 10.0E-6           $" Dif. Model Time Constant(sec)"
" The 42 Volt Battery Load Dump Test Parameters "
" RLD42 = Load Equivalent Resistance During Battery Load Dump(Ohms)"
CONSTANT RLD42  = 1.0
" TLD42 = 42V Load Dump Test Starting Time (Sec) "
CONSTANT TLD42 = 1.0
" SWLD42 = 42V Load Dump Switch "
" SWLD42 = 0.0, 42V Load Dump Switch is OFF "
" SWLD42 = 1.0, 42V Load Dump Switch is ON "
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CONSTANT SWLD42 = 0.0
" Rectifier Parameters "
" Avalanche Diode Forward and Reverse Conduction Table "
" VD    = VDT(I)          (Volts) "
TABLE VDT, 1, 11,...
-100.0,-55.0,-35.0,-25.0,-15.0,-0.1, 0.0, 0.1, 35.0, 50.0, 100.0,...
-95.0,-95.0,-95.0,-94.0,-93.0,-92.0, 0.0, 0.85, 0.90, 0.95, 0.95
" Lithium Polymer Battery Parameters "
" Electric Analog Circuit Parameters "
" Battery Storage Capacitance Parameters "
CONSTANT VCMN   = 3.7             $" Minimum Cell Voltage (Volts) "
CONSTANT VCMX   = 4.7             $" Maximum Cell Voltage (Volts) "
" CSBT  = Battery Storage Capacitance (F) vs Current (Amps) "
TABLE CSBT, 1, 13,...
-200.0, -100.0, -75.0, -50.0, -25.0, -5.0, 0.0,...
 5.0, 25.0, 50.0, 75.0, 100.0, 200.0,...
 4.0E+5, 4.0E+5, 3.5E+5, 3.0E+5, 2.25E+5, 2.25E+5, 1.0E+5,...
 2.25E+5, 2.25E+5, 3.0E+5, 3.5E+5, 4.0E+5, 4.0E+5
" CSBLT = Limited Battery Storage Capacitance (F) vs Current (Amps) "
TABLE CSBLT, 1, 13,...
-200.0, -100.0, -75.0, -50.0, -25.0, -5.0, 0.0,...
5.0, 25.0, 50.0, 75.0, 100.0, 200.0,...
4.5E+4, 4.5E+4, 2.5E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4,...
3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4
" VCON1 = Cell-1 Maximum Voltage (Volts) "
CONSTANT VCON1   = 4.2
" VCON2 = Cell-2 Maximum voltage (Volts) "
CONSTANT VCON2   = 4.2
" VCON3 = Cell-3 Maximum Voltage (Volts) "
CONSTANT VCON3   = 4.2
" VCON4 = Cell-4 Maximum Voltage (Volts) "
CONSTANT VCON4   = 4.2
" VCON5 = Cell-5 Maximum Voltage (Volts) "
CONSTANT VCON5   = 4.2
" VCON6 = Cell-6 Maximum Voltage (Volts) "
CONSTANT VCON6   = 4.2
" VCON7 = Cell-7 Maximum Voltage (Volts) "
CONSTANT VCON7   = 4.2
" VCON8 = Cell-8 Maximum Voltage (Volts) "
CONSTANT VCON8   = 4.2
" VCON9 = Cell-9 Maximum Voltage (Volts) "
CONSTANT VCON9   = 4.2
" VCON10= Cell-10 Maximum Voltage (Volts)"
CONSTANT VCON10  = 4.2
" RIB  = Battery Internal Resistance (Ohms) "
" RIB varies with TIB = Interior Battery Temperature "
" TIB  = Interior Battery Temperature (Deg C) "
" CFRBT= Temperature Correction Factor for TIB "
" Cell Resistance values at 25 Deg C (Ohms) "
CONSTANT RIC1I = 0.00250, RLC1I = 4.65E+3, RCON1I = 36.0   $" Cell-1 "
CONSTANT RIC2I = 0.00250, RLC2I = 4.65E+3, RCON2I = 36.0   $" Cell-2 "
CONSTANT RIC3I = 0.00250, RLC3I = 4.65E+3, RCON3I = 36.0   $" Cell-3 "
CONSTANT RIC4I = 0.00250, RLC4I = 4.65E+3, RCON4I = 36.0   $" Cell-4 "
CONSTANT RIC5I = 0.00250, RLC5I = 4.65E+3, RCON5I = 36.0   $" Cell-5 "
CONSTANT RIC6I = 0.00250, RLC6I = 4.65E+3, RCON6I = 36.0   $" Cell-6 "
CONSTANT RIC7I = 0.00250, RLC7I = 4.65E+3, RCON7I = 36.0   $" Cell-7 "
CONSTANT RIC8I = 0.00250, RLC8I = 4.65E+3, RCON8I = 36.0   $" Cell-8 "
CONSTANT RIC9I = 0.00250, RLC9I = 4.65E+3, RCON9I = 36.0   $" Cell-9 "
CONSTANT RIC10I= 0.00250, RLC10I= 4.65E+3, RCON10I= 36.0   $" Cell-10"
TABLE CFRBT, 1, 7,...
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-45.0, -29.0, -18.0, 0.0, 25.0, 52.0, 75.0,...
 3.0, 3.0, 2.0, 1.2, 1.0, 1.0, 1.0
" Initial Values of State Variables "
CONSTANT AHBZ = 19.50        $" Initial Battery AH Capacity "
" AHBR = Battery Ampere-Hour Rating "
CONSTANT AHBR = 35.0
" Cell Open-Circuit Voltages (Volts) "
CONSTANT VOCC1Z = 4.05, VOCC2Z = 4.05, VOCC3Z = 4.05, VOCC4Z = 4.05,...
CONSTANT VOCC5Z = 4.05, VOCC6Z = 4.05, VOCC7Z = 4.05, VOCC8Z = 4.05,...
CONSTANT VOCC9Z = 4.05, VOCC10Z = 4.05
" CELCON = Cell Controller Logic Macro "
" CELCON Definition "
  MACRO PMACRO CELCON, P
  IF(P(2).GE.P(3))     THEN
      P(1)    =  1.0
  ELSE
      P(1)    =  0.0
  ENDIF
  MACRO END
" CELCAP = Cell Capacitance Selection Logic "
" CELCAP Definition "
  MACRO PMACRO CELCAP, P
  IF(P(3).LE.P(2).AND.P(2).LE.P(4))      THEN
     P(1) = P(5)
  ELSEIF(P(2).LT.P(3).OR.P(2).GT.P(4)) THEN
     P(1) = P(6)
  ENDIF
  MACRO END
" CELCOM1 = LiPo Battery Cell Computation Macro "
" CELCOM1 Definition "
  MACRO MACRO CELCOM1, P
  P(2)    = P(5)-P(6)-P(7)
  P(3)    = (1.0/P(8))*P(2)
  P(1)    = INTEG(P(3), P(9))
  P(4)    = P(10)*P(5)**2 + P(11)*P(6)**2 + P(12)*P(7)**2
  MACRO END
" Thermal Model Parameters "
" MPOLY  = Electrolyte Mass (kg)"
" CPPOLY = Electrolyte Specific Heat (Joules/kg-deg C) "
CONSTANT MPOLY  = 1.9 , CPPOLY  = 1590.0
" MCOP   = Copper Mesh Mass (kg)"
" CPCOP  = Copper Mesh Specific Heat  (Joules/kg-deg C)"
CONSTANT MCOP   = 1.37, CPCOP   = 381.0
" MALUM  = Aluminum Mesh Mass (kg) "
" CPALUM = Aluminum Mesh Specific Heat (Joules/kg-deg C) "
CONSTANT MALUM  = 0.150, CPALUM = 870.0
" MSTL   = Steel Mass (kg) "
" CPSTL  = Steel Specific Heat (Joules/kg-deg C) "
CONSTANT MSTL   = 0.140, CPSTL  = 477.0
" Battery Plastic Can Parameters "
CONSTANT THKB   = 3.0        $" Thickness(mm) "
CONSTANT KSB    = 1.903E-4   $" Conductance Coefficient(Watts/mm-deg C)"
CONSTANT ASB    = 8.48E+5    $" Surface Area (mm**2) "
" MSB14 = Surface Mass (kg) "
CONSTANT  MSB   = 10.0
" CPS   = Surface Specific Heat (Joules/kg-deg C) "
CONSTANT CPSB   = 1590.0
" KOB14 = Convective Heat Transfer Coefficient(Watts/mm**2-Deg C)"
CONSTANT KOB    = 156.45E-6
" Initial Conditions on State Variables "
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CONSTANT TIBZ    = 25.0,  TSBZ = 25.0  $" Deg C "
" TOB14 = Outside Air Temperature "
CONSTANT TOB     = 25.0                $" Deg C "
" DC-DC Buck Converter Parameters "
" DCYCLE = Duty Cycle = fraction between 0 and 1 "
CONSTANT DCYCLE = 0.338
" ILOAD = Load Demand Current (Amperes) "
CONSTANT ILOAD = 0.0
" TSLOAD = Load Starting Time (sec) "
CONSTANT TSLOAD = 10.0E-6
" IDISCH, IHKEEP = Estimated Current Leakages (Amperes) "
CONSTANT IDISCH = 0.400, IHKEEP = 1.09
" Circuit Parameters "
" R3 = Transistor 3 ON  Resistance (Ohms) "
CONSTANT R3 = 2.0E-3
" Input Filter "
" L30 = Inductance(H), R30 = Resistance(Ohm), C30 = Capacitance(F) "
CONSTANT L30  = 2.0E-6, R30  =  50.0E-3, C30 = 20.0E-6
" Output Filter "
" L45 = Inductance(H), R50 = Resistance(Ohm), C50 = Capacitance(F) "
CONSTANT L45  = 2.0E-6, R50  =  50.0E-3, C50 = 50.0E-6
" R52 = Output Resistance (Ohm) "
CONSTANT R52  = 13.4E-3
" Initial Conditions "
CONSTANT I1Z = 0.0, IL45Z = 0.0
" Lead Acid Parameters "
CONSTANT RICB14 = 30.0E-3, RLCB14 = 4.50E+3, CSCB14 = 2.0E+5
CONSTANT AHB14Z = 55.20     $" Initial Battery AH Capacity "
CONSTANT AHB14R = 69.0      $" Battery AH Rating "
" Initial Cell Resistance Values in Ohms at 25 Deg C "
CONSTANT RIC1B14I = 0.005, RLC1B14I = 750.0     $" Cell-1 "
CONSTANT RIC2B14I = 0.005, RLC2B14I = 750.0     $" Cell-2 "
CONSTANT RIC3B14I = 0.005, RLC3B14I = 750.0     $" Cell-3 "
CONSTANT RIC4B14I = 0.005, RLC4B14I = 750.0     $" Cell-4 "
CONSTANT RIC5B14I = 0.005, RLC5B14I = 750.0     $" Cell-5 "
CONSTANT RIC6B14I = 0.005, RLC6B14I = 750.0     $" Cell-6 "
" VCMNB14, VCMXB14 = Minimum, Maximum Cell Voltage Limits(V) "
CONSTANT VCMNB14  = 1.9, VCMXB14 = 2.45
" CSB14 = Battery Storage Capacitance(F) vs Current(A) "
TABLE CSB14T, 1, 11,...
-100.0,-50.0,-25.0,-15.0,-3.45, 0.0, 3.45, 15.0, 25.0, 50.0,100.0,...
12.5E+5, 12.5E+5, 12.5E+5, 10.0E+5, 10.0E+5, 5.0E+5, 2.5E+5,...
2.25E+5, 2.5E+5, 1.5E+5, 1.5E+5
" CSB14L = Limited Battery Storage Capacitance(F) vs Current(A) "
TABLE CSB14LT, 1, 11,...
-100.0,-50.0,-25.0,-15.0,-3.45, 0.0, 3.45, 15.0, 25.0, 50.0, 100.0,..
1.25E+5, 1.25E+5, 1.25E+5, 1.0E+5, 1.0E+5, 0.5E+5, 0.05E+5,...
0.05E+5, 0.1E+5, 0.05E+5, 0.05E+5
" Cell Voltage Initial Values "
CONSTANT VOC1B14Z = 2.25, VOC2B14Z = 2.25, VOC3B14Z = 2.25
CONSTANT VOC4B14Z = 2.25, VOC5B14Z = 2.25, VOC6B14Z = 2.25
" CELCOM2 = Lead Acid Battery Cell Computation Macro 2 "
" CELCOM2 Definition "
MACRO MACRO CELCOM2, P
P(2)    = P(5)-P(6)
P(3)    = (1.0/P(7))*P(2)
P(1)    = INTEG(P(3), P(8))
P(4)    = P(9)*P(5)**2+P(10)*P(6)**2
MACRO END
" Thermal Model Parameters "
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" MACID = Acid Mass (kg), CPACID = Specific Heat(Joules/kg-deg C) "
CONSTANT MACID = 5.73, CPACID = 2.11E+3
" MLEAD = Lead Mass (kg), CPLEAD = Specific Heat(Joules/kg-deg C) "
CONSTANT MLEAD = 9.67, CPLEAD = 128.0
" Battery Plastic Can Parameters "
CONSTANT THKB14 = 3.0        $" Thickness(mm) "
CONSTANT KSB14  = 1.903E-4   $" Conductance Coefficient(Watts/mm-deg C)"
CONSTANT ASB14  = 3.548E+5   $" Surface Area (mm**2)"
" MSB14 = Can Mass(kg) "
CONSTANT MSB14  = 1.865
" CPSB14= Surface Specific heat(Joules/kg-deg C) "
CONSTANT CPSB14 = 1590.0
" KOB14 = Convective Heat Transfer Coefficient(Watts/mm**2-deg C) "
CONSTANT KOB14  = 156.4E-6
" Initial Conditions on State Variables "
CONSTANT TIB14Z = 25.0, TSB14Z = 25.0   $" Deg C "
" TOB14 = Outside Air Temperature "
CONSTANT TOB14  = 25.0                  $" Deg C "
" Initial Region Computations "
INITIAL
" General Computed Parameters "
PI      = ACOS(-1.0)
" Generator Computed Parameters "
TEC1    = TEACC+TERISE
TEDEC   = TEC1+TESS
TEC2    = TEDEC+TEFALL
" LiPo Battery Computed Parameters "
" Thermal model Computed Parameters "
" CTHIB = Battery Interior Thermal Capacitance (Watt-Sec/deg C) "
CTHIB   = MPOLY*CPPOLY+MCOP*CPCOP+MALUM*CPALUM+MSTL*CPSTL
" RSB   = Surface Conductive Heat Transfer Resistance(deg C/Watts)"
RSB     = THKB/(KSB*ASB)
" CTHSB = Battery Surface Thermal Capacitance (Watt-Sec/deg C) "
CTHSB   = MSB*CPSB
" ROB   = Surface Convective Heat Transfer Coefficient(deg C/Watts) "
ROB     = 1.0/(KOB*ASB)
" DC-DC Converter Computed Parameters "
VC30Z   = VOCC1Z+VOCC2Z+VOCC3Z+VOCC4Z+VOCC5Z+VOCC6Z+VOCC7Z...
                                          +VOCC8Z+VOCC9Z+VOCC10Z
VOCB14Z = VOC1B14Z+VOC2B14Z+VOC3B14Z+VOC4B14Z+VOC5B14Z+VOC6B14Z
VC50Z   = VOCB14Z
" Lead Acid Battery Computed Parameters "
" Thermal Model Computed Parameters "
" CTHIB14= Battery Interior Thermal Capacitance (Watt-sec/Deg C) "
CTHIB14 = MACID*CPACID+MLEAD*CPLEAD
" RSB14 = Surface Conductive Heat Transfer Resistance(Deg C/Watts) "
RSB14   = THKB14/(KSB14*ASB14)
" CTHSB14= Battery Surface Thermal Capacitance(Watt-sec/Deg C) "
CTHSB14 = MSB14*CPSB14
" ROB14 = Surface Convective Heat Transfer Coefficient (Deg C/Watts) "
ROB14   = 1.0/(KOB14*ASB14)
END INITIAL
                  " Dynamic and Derivative Region Computations "
DYNAMIC
 DERIVATIVE EQS
                  " Simulation Controls "
 ALGORITHM ISTART = 5, IRUN = 5
 CINTERVAL CI    = 1.0E-6
 NSTEPS    NST   = 2
 MINTERVAL HMINT = 1.0E-20
```

```
" Engine Speed Command Model "
PROCEDURAL (NENGS = T)
  IF(T.LT.TEACC)                          THEN
    NENGS    = 0.0
  ELSEIF(TEACC.LE.T.AND.T.LT.TEC1)        THEN
    NENGS    = NEACC
  ELSEIF(TEC1.LE.T.AND.T.LT.TEDEC)        THEN
    NENGS    =  0.0
  ELSEIF(TEDEC.LE.T.AND.T.LT.TEC2)        THEN
    NENGS    = NEDEC
  ELSEIF(T.GE.TEC2)                       THEN
    NENGS    =  0.0
  ENDIF
END
NENG  = INTEG(NENGS,NEZ)
" NGEN     = Generator Speed (rpm) "
" MODTEST = 1.0 Generator Test is On "
" MODTEST = 0.0 Generator Test is Off "
PROCEDURAL(NGEN = MODTEST, NENG, NEZ)
  IF(MODTEST.LT.0.5)        THEN
     NGEN    = GRGEN*NENG
  ELSEIF(MODTEST.GE.0.5)    THEN
     NGEN    = GRGEN*NEZ
  ENDIF
END
" Voltage Regulator Model "
" VSAW   = Sawtooth Voltage (Volt) "
VSAW    = AMPSAW*SAWTT(AMOD(T,SAWPER))
" VDFW = Field Free Wheeling Diode Voltage Drop(Volts) "
VDFW    = VDFWT(IFGEN)
VGBFBK = VTB42
VSEN    = 0.333*VGBFBK
VREF    = VREFDC+VSAW
VERR    = VREF-VSEN
LFGEN   = LFGENT(IFGEN)
RFGEN   = RFGENO*(1.0+ALPHAW*(TIG-TIGREF))
" IFGENS = Field Current Derivative (amp/sec)"
" VFCON  = Field PWM Control Voltage (Volts) "
PROCEDURAL(IFGENS,VFCON = VERR,VSREG,LFGEN,RFGEN,LAMFSC,VDFW,MODCON
  IF(VERR.GE.0.0)                                  THEN
    VFCON   = VSREG
    IFGENS = (1.0/LFGEN)*(VFCON-VBRDROP-RFGEN*IFGEN-LAMFSC)*MODCON
  ELSEIF(VERR.LT.0.0)                              THEN
    VFCON   = 0.0
    IFGENS = (1.0/LFGEN)*(VFCON-RFGEN*IFGEN-LAMFSC-VDFW)*MODCON
  ENDIF
END
IFGEN   = INTEG(IFGENS,IFGENZ)
" LEC Controller Model "
PROCEDURAL(VLEC = VGBCON)
  IF(VGBCON.LE.VLECNL)        THEN
     VLEC = 1.0
  ELSE
     VLEC = 0.0
  ENDIF
END
" Generator Model "
" OMGGEN  = Generator Electric Frequency (rad/sec) "
OMGGEN = NGEN*(2.0*PI/60.0)*NPPGEN
" Computation of Circuit Parameters "
```

```
" Stator Phase Resistances (Ohms) "
RAGEN  = RAGENO*(1.0+ALPHAW*(TIG-TIGREF))
RBGEN  = RBGENO*(1.0+ALPHAW*(TIG-TIGREF))
RCGEN  = RCGENO*(1.0+ALPHAW*(TIG-TIGREF))
" Stator-Field Mutual Inductances (Henry) "
LMFA   = LMFT(IFGEN,NGEN)
LMFB   = LMFA
LMFC   = LMFA
" LAMF  = Field flux induced by phase currents (Weber) "
" LAMFS = Field Voltage induced by phase currents (Volts)"
" LAMFSC= Computed LAMFS "
LAMF   = LMFA*COS(OMGGEN*T)*IAGEN+...
         LMFB*COS(OMGGEN*T-(2.0*PI/3.0))*IBGEN+...
         LMFC*COS(OMGGEN*T+(2.0*PI/3.0))*ICGEN
LAMFSC = (1.0/TAUDIF)*(LAMF-LAMFC)
LAMFC  = INTEG(LAMFSC, 0.0)
" Compute Synchronous Inductances (Henry) "
LSA    = LST(NGEN)
LSB    = LSA
LSC    = LSA
" Back emf Voltages "
" VAGEN = Field-Phase A Back EMF Voltage (Volts) "
VMFA   = LMFA*COS(OMGGEN*T)*IFGENS
VAGEN  = OMGGEN*LMFA*SIN(OMGGEN*T)*IFGEN-VMFA
" VBGEN = Field-Phase B Back EMF Voltage (Volts) "
VMFB   = LMFB*COS(OMGGEN*T-(2.0*PI/3.0))*IFGENS
VBGEN  = OMGGEN*LMFB*SIN(OMGGEN*T-(2.0*PI/3.0))*IFGEN-VMFB
" VCGEN = Field-Phase C Back EMF Voltage (Volts) "
VMFC   = LMFC*COS(OMGGEN*T+(2.0*PI/3.0))*IFGENS
VCGEN  = OMGGEN*LMFC*SIN(OMGGEN*T+(2.0*PI/3.0))*IFGEN-VMFC
" VGENPK = Peak back emf Voltage (Volts) "
" VGENXR = Phase Voltage Crossing Level (Volts) "
VGENPK = OMGGEN*LMFA*IFGEN
VGENXR = 0.5*VGENPK
" VSUMGEN = Generator Voltages Sum "
VSUMGEN= VAGEN + VBGEN + VCGEN
" VGB42 = Generator Bus voltage Computation (Volts) "
" VTB42 = Battery Terminal Voltage (Volts) "
VGB42  = VTB42+2.0*VDT(ISGEN)
" Computation of Delta Winding Line-to-Line Voltages "
" VABGEN Computation "
PROCEDURAL(VABGEN = VAGEN,VBGEN,VCGEN,VGB42,VGENPK,VGENXR)
 IF(VGENPK.LE.VGB42.AND.VGENXR.LE.VGB42)                          THEN
      VABGEN   = VAGEN
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VAGEN.GE.0.0...
                                          .AND.VCGEN.LE.0.0)      THEN
      VABGEN   = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VBGEN.GT.VCGEN...
                                          .AND.VAGEN.GT.VCGEN)    THEN
      VABGEN   = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VAGEN.LE.0.0...
                                          .AND.VCGEN.LE.0.0)      THEN
      VABGEN   = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VAGEN.LE.VCGEN...
                                          .AND.VCGEN.LE.VBGEN)    THEN
      VABGEN   = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VAGEN.LE.0.0...
                                          .AND.VCGEN.GE.0.0)      THEN
      VABGEN   = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VBGEN.LT.VCGEN...
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                                                    .AND.VAGEN.LT.VCGEN)    THEN
      VABGEN    = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VAGEN.GE.0.0...
                                                    .AND.VCGEN.GE.0.0)      THEN
      VABGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VAGEN.GE.VCGEN...
                                                    .AND.VCGEN.GE.VBGEN)    THEN
      VABGEN    = 0.0
 ENDIF
END
" VBCGEN Computation "
PROCEDURAL(VBCGEN = VAGEN,VBGEN,VCGEN,VGB42,VGENPK,VGENXR)
 IF(VGENPK.LE.VGB42.AND.VGENXR.LE.VGB42)                                    THEN
      VBCGEN    = VBGEN
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VBGEN.GE.0.0...
                                                    .AND.VAGEN.LE.0.0)      THEN
      VBCGEN    = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VCGEN.GT.VAGEN...
                                                    .AND.VBGEN.GT.VAGEN)    THEN
      VBCGEN    = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VBGEN.LE.0.0...
                                                    .AND.VAGEN.LE.0.0)      THEN
      VBCGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VBGEN.LE.VAGEN...
                                                    .AND.VAGEN.LE.VCGEN)    THEN
      VBCGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VBGEN.LE.0.0...
                                                    .AND.VAGEN.GE.0.0)      THEN
      VBCGEN    = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VCGEN.LT.VAGEN...
                                                    .AND.VBGEN.LT.VAGEN)    THEN
      VBCGEN    = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VBGEN.GE.0.0...
                                                    .AND.VAGEN.GE.0.0)      THEN
      VBCGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VCGEN.LE.VAGEN...
                                                    .AND.VAGEN.LE.VBGEN)    THEN
      VBCGEN    = 0.0
 ENDIF
END
" VCAGEN Computation "
PROCEDURAL(VCAGEN = VAGEN,VBGEN,VCGEN,VGB42,VGENPK,VGENXR)
 IF(VGENPK.LE.VGB42.AND.VGENXR.LE.VGB42)                                    THEN
      VCAGEN    = VCGEN
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VCGEN.GE.0.0...
                                                    .AND.VBGEN.LE.0.0)      THEN
      VCAGEN    = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VAGEN.GT.VBGEN...
                                                    .AND.VCGEN.GT.VBGEN)    THEN
      VCAGEN    = VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VCGEN.LE.0.0...
                                                    .AND.VBGEN.LE.0.0)      THEN
      VCAGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VCGEN.LE.VBGEN...
                                                    .AND.VBGEN.LE.VAGEN)    THEN
      VCAGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VCGEN.LE.0.0...
                                                    .AND.VBGEN.GE.0.0)      THEN
      VCAGEN    = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VAGEN.LT.VBGEN...
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                                                    .AND.VCGEN.LT.VBGEN)    THEN
      VCAGEN    = -VGB42
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.LE.VGB42.AND.VCGEN.GE.0.0...
                                                    .AND.VBGEN.GE.0.0)      THEN
      VCAGEN    = 0.0
 ELSEIF(VGENPK.GT.VGB42.AND.VGENXR.GT.VGB42.AND.VAGEN.LE.VBGEN...
                                                    .AND.VBGEN.LE.VCGEN)    THEN
      VCAGEN    = 0.0
 ENDIF
END
VLSUMGEN= VABGEN+VBCGEN+VCAGEN
" Computation of Generator Stator Phase Currents (Amps) "
" IAGEN, IBGEN, ICGEN Computation "
IAGENS   = (1.0/LSA)*(VAGEN-VABGEN-RAGEN*IAGEN)
IAGEN    = INTEG(IAGENS, 0.0)
IBGENS   = (1.0/LSB)*(VBGEN-VBCGEN-RBGEN*IBGEN)
IBGEN    = INTEG(IBGENS, 0.0)
ICGENS   = (1.0/LSC)*(VCGEN-VCAGEN-RCGEN*ICGEN)
ICGEN    = INTEG(ICGENS, 0.0)
" ISUMGEN= Sum of Generator Phase Currents "
ISUMGEN  = IAGEN+IBGEN +ICGEN
" Compute Line Currents IALGEN, IBLGEN, ICLGEN "
IALGEN   = IAGEN - ICGEN
IBLGEN   = IBGEN - IAGEN
ICLGEN   = ICGEN - IBGEN
" ILSUMGEN = Sum of Generator Line Currents '
ILSUMGEN = IALGEN+IBLGEN+ICLGEN
" Compute Generator Rectified DC Current ISGEN "
PROCEDURAL (IADCGEN = IALGEN)
  IF (IALGEN.GE.0.0)  THEN
     IADCGEN = IALGEN
  ELSE
     IADCGEN = 0.0
  ENDIF
END
PROCEDURAL (IBDCGEN = IBLGEN)
  IF (IBLGEN.GE.0.0)  THEN
     IBDCGEN = IBLGEN
  ELSE
     IBDCGEN = 0.0
  ENDIF
END
PROCEDURAL (ICDCGEN = ICLGEN)
  IF (ICLGEN.GE.0.0)  THEN
     ICDCGEN = ICLGEN
  ELSE
     ICDCGEN = 0.0
  ENDIF
END
ISGEN  = IADCGEN + IBDCGEN + ICDCGEN
" Computation of Generator Torque (Nm) "
" PWGEN = Generator Power Output (Watts) "
" TQGEN = Generator Electrical Torque (Nm) "
PWGEN    = (VAGEN*IAGEN+VBGEN*IBGEN+VCGEN*ICGEN)
TQGEN    = PWGEN/(NGEN*(2.0*PI/60.0)+1.0)
" PWLSGEN = Stator Power Loss (Watts) "
PWLSGEN = RAGEN*IAGEN**2+RBGEN*IBGEN**2+RCGEN*ICGEN**2
" PWLFGEN = Field Power Loss (Watts) "
PWLFGEN  = RFGEN*IFGEN**2
" PWLRGEN = Rectifier Power Loss (Watts) "
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```
PWLDA   = VDT(IADCGEN)*IADCGEN
PWLDB   = VDT(IBDCGEN)*IBDCGEN
PWLDC   = VDT(ICDCGEN)*ICDCGEN
PWLRGEN= PWLDA+PWLDB+PWLDC
" PWBUS = Generator Power Output at the Bus (Watts)"
PWBUS   = VGB42*ISGEN
" Generator Thermal Model "
 TIG     = 25.0
 " 42 Volt Loads "
 " ISM   = Starter Motor Load Current (Amps) "
 ISM     = ISMAMP*( STEP(TSMON,T)-STEP(TSMOFF,T))
 " PWLSM = Starter Motor Power Loss (Watts) "
 PWLSM   = RSM*ISM**2
 " PWSM  = Starter Motor Power Output (Watts) "
 " TSM   = Motor Torque (Nm) "
 TSM     = KTSM*ISM
 PWSM    = TSM*(NEZ*(2.0*PI/60.0))
 " IPSM = Power Steering Motor Load Current (Amps) "
 PROCEDURAL(IPSM = T)
   IF(T.LT.TPSMON)                          THEN
      IPSM    =  0.0
   ELSEIF(TPSMON.LE.T.AND.T.LT.TPSMOFF)    THEN
      IPSM    = IPSMAMP*( STEP(TPSMON,T)- STEP(TPSMOFF,T))
   ELSE
      IPSM    =  0.0
   ENDIF
 END
 " PWLPSM = Power Steering Motor Power Loss (Watts) "
 PWLPSM  = RPSM*IPSM**2
 " PWPSM = Power Steering Motor Power Output (Watts) "
 " TPSM  = Motor Torque (Nm) "
 TPSM    = KTPSM*IPSM
 PWPSM   = TPSM*OMGPS
 " LiPo Battery Model "
 " State Equations for the electric analog circuit model "
 " Positive Current = Charge, Negative Current = Discharge "
 " CFRC = Resistance Correction Factor "
 CFRC    = CFRBT(TIB)
 " Battery Discharge/Charge Current and Terminal Voltage Computation "
 VOCCB42 =VOCC10+VOCC9+VOCC8+VOCC7+VOCC6+VOCC5+VOCC4+VOCC3+VOCC2+VOCC1
 RICB42  = RIC10+RIC9+RIC8+RIC7+RIC6+RIC5+RIC4+RIC3+RIC2+RIC1
 PROCEDURAL(IBC10,VTB42,ILD42 = T,TLD42,SWLD42,ISGEN,ISM,IPSM,I1,...
                                VOCCB42,RICB42)
   IF(T.LT.TLD42.AND.SWLD42.LT.0.5)                              THEN
     IBC10 = (ISGEN-ISM-IPSM-I1)
     VTB42 = VOCCB42+RICB42*IBC10
     ILD42 = 0.0
   ELSEIF(T.GE.TLD42.AND.SWLD42.LT.0.5)                          THEN
     IBC10 = (ISGEN-ISM-IPSM-I1)
     VTB42 = VOCCB42+RICB42*IBC10
     ILD42 = 0.0
   ELSEIF(T.LT.TLD42.AND.SWLD42.GT.0.5)                          THEN
     IBC10 = (1.0/(1.0+(RICB42/RLD42)))*(ISGEN-ISM-IPSM-...
                                    I1*(1.0-SWLD42)-(VOCCB42/RLD42))
     VTB42 = VOCCB42+RICB42*IBC10
     ILD42 = (VTB42/RLD42)
   ELSEIF(T.GE.TLD42.AND.SWLD42.GT.0.5)                          THEN
     IBC10 = 0.0
     VTB42 = RLD42*(ISGEN-ISM-IPSM-I1*(1.0-SWLD42))
     ILD42 = (VTB42/RLD42)
```

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  ENDIF
END
" Computation of Battery Storage Capacitances "
CSB     = CSBT(IBC10)
CSBL    = CSBLT(IBC10)
" Cell-10 "
SWC10   = CELCON(VC10,VCON10)
VOCC10,ICC10,VOCC10S,PWLC10 = CELCOM1(IBC10,ILC10,ICON10,CSC10,...
                                      VOCC10Z,RIC10,RLC10,RCON10)
CSC10   = CELCAP(VC10,VCMN,VCMX,CSB,CSBL)
RIC10   = CFRC*RIC10I
RLC10   = CFRC*RLC10I
ILC10   = (VOCC10/RLC10)
RCON10  = CFRC*RCON10I
ICON10  = (SWC10*VOCC10)/RCON10
VC10    = VOCC10+ RIC10*IBC10
VB10    = VC10+VB9
" Cell-9 "
IBC9    = ICC10
SWC9    = CELCON(VC9,VCON9)
VOCC9,ICC9,VOCC9S,PWLC9 = CELCOM1(IBC9,ILC9,ICON9,CSC9,...
                                  VOCC9Z,RIC9,RLC9,RCON9)
CSC9    = CELCAP(VC9,VCMN,VCMX,CSB,CSBL)
RIC9    = CFRC*RIC9I
RLC9    = CFRC*RLC9I
ILC9    = (VOCC9/RLC9)
RCON9   = CFRC*RCON9I
ICON9   = (SWC9*VOCC9)/RCON9
VC9     = VOCC9+ RIC9*IBC9
VB9     = VC9+VB8
" Cell-8 "
IBC8    = ICC9
SWC8    = CELCON(VC8,VCON8)
VOCC8,ICC8,VOCC8S,PWLC8 = CELCOM1(IBC8,ILC8,ICON8,CSC8,...
                                  VOCC8Z,RIC8,RLC8,RCON8)
CSC8    = CELCAP(VC8,VCMN,VCMX,CSB,CSBL)
RIC8    = CFRC*RIC8I
RLC8    = CFRC*RLC8I
ILC8    = (VOCC8/RLC8)
RCON8   = CFRC*RCON8I
ICON8   = (SWC8*VOCC8)/RCON8
VC8     = VOCC8+ RIC8*IBC8
VB8     = VC8+VB7
" Cell-7 "
IBC7    = ICC8
SWC7    = CELCON(VC7,VCON7)
VOCC7,ICC7,VOCC7S,PWLC7 = CELCOM1(IBC7,ILC7,ICON7,CSC7,...
                                  VOCC7Z,RIC7,RLC7,RCON7)
CSC7    = CELCAP(VC7,VCMN,VCMX,CSB,CSBL)
RIC7    = CFRC*RIC7I
RLC7    = CFRC*RLC7I
ILC7    = (VOCC7/RLC7)
RCON7   = CFRC*RCON7I
ICON7   = (SWC7*VOCC7)/RCON7
VC7     = VOCC7+RIC7*IBC7
VB7     = VC7+VB6
" Cell-6 "
IBC6    = ICC7
SWC6    = CELCON(VC6,VCON6)
VOCC6,ICC6,VOCC6S,PWLC6 = CELCOM1(IBC6,ILC6,ICON6,CSC7,...
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                                                VOCC6Z,RIC6,RLC6,RCON6)
CSC6    = CELCAP(VC6,VCMN,VCMX,CSB,CSBL)
RIC6    = CFRC*RIC6I
RLC6    = CFRC*RLC6I
ILC6    = (VOCC6/RLC6)
RCON6   = CFRC*RCON6I
ICON6   = (SWC6*VOCC6)/RCON6
VC6     = VOCC6+ RIC6*IBC6
VB6     = VC6+ VB5
" Cell-5 "
IBC5    = ICC6
SWC5    = CELCON(VC5,VCON5)
VOCC5,ICC5,VOCC5S,PWLC5 = CELCOM1(IBC5,ILC5,ICON5,CSC5,...
                                                VOCC5Z,RIC5,RLC5,RCON5)
CSC5    = CELCAP(VC5,VCMN,VCMX,CSB,CSBL)
RIC5    = CFRC*RIC5I
RLC5    = CFRC*RLC5I
ILC5    = (VOCC5/RLC5)
RCON5   = CFRC*RCON5I
ICON5   = (SWC5*VOCC5)/RCON5
VC5     = VOCC5+RIC5*IBC5
VB5     = VC5+ VB4
" Cell-4 "
IBC4    = ICC5
SWC4    = CELCON(VC4,VCON4)
VOCC4,ICC4,VOCC4S,PWLC4 = CELCOM1(IBC4,ILC4,ICON4,CSC4,...
                                                VOCC4Z,RIC4,RLC4,RCON4)
CSC4    = CELCAP(VC4,VCMN,VCMX,CSB,CSBL)
RIC4    = CFRC*RIC4I
RLC4    = CFRC*RLC4I
ILC4    = (VOCC4/RLC4)
RCON4   = CFRC*RCON4I
ICON4   = (SWC4*VOCC4)/RCON4
VC4     = VOCC4+RIC4*IBC4
VB4     = VC4+ VB3
" Cell-3 "
IBC3    = ICC4
SWC3    = CELCON(VC3,VCON3)
VOCC3,ICC3,VOCC3S,PWLC3 = CELCOM1(IBC3,ILC3,ICON3,CSC3,...
                                                VOCC3Z,RIC3,RLC3,RCON3)
CSC3    = CELCAP(VC3,VCMN,VCMX,CSB,CSBL)
RIC3    = CFRC*RIC3I
RLC3    = CFRC*RLC3I
ILC3    = (VOCC3/RLC3)
RCON3   = CFRC*RCON3I
ICON3   = (SWC3*VOCC3)/RCON3
VC3     = VOCC3 + RIC3*IBC3
VB3     = VC3 + VB2
" Cell-2 State Equations "
IBC2    = ICC3
SWC2    = CELCON(VC2,VCON2)
VOCC2,ICC2,VOCC2S,PWLC2 = CELCOM1(IBC2,ILC2,ICON2,CSC2,...
                                                VOCC2Z,RIC2,RLC2,RCON2)
CSC2    = CELCAP(VC2,VCMN,VCMX,CSB,CSBL)
RIC2    = CFRC*RIC2I
RLC2    = CFRC*RLC2I
ILC2    = (VOCC2/RLC2)
RCON2   = CFRC*RCON2I
ICON2   = (SWC2*VOCC2)/RCON2
VC2     = VOCC2+ RIC2*IBC2
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VB2      = VC2+VB1
" Cell-1 State Equations "
IBC1     = ICC2
SWC1     = CELCON(VC1,VCON1)
VOCC1,ICC1,VOCC1S,PWLC1 = CELCOM1(IBC1,ILC1,ICON1,CSC1,...
                                  VOCC1Z,RIC1,RLC1,RCON1)
CSC1     = CELCAP(VC1,VCMN,VCMX,CSB,CSBL)
RIC1     = CFRC*RIC1I
RLC1     = CFRC*RLC1I
ILC1     = (VOCC1/RLC1)
RCON1    = CFRC*RCON1I
ICON1    = (SWC1*VOCC1)/RCON1
VC1      = VOCC1+ RIC1*IBC1
VB1 = VC1
" AHB    = Net Battery Ampere-Hour Capacity (AH) "
AHBS     = (1.0/3600.0)*ICC10
AHB      = INTEG(AHBS,AHBZ)
" State Of Charge (SOC) "
SOC    = (AHB/AHBR)
" Power Computations "
" PWBC  = Power at the Battery Output (Watts) "
PWBC     = VB10*IBC10
" State Equations for the Thermal Model "
" TIBS  = Rate of Interior Battery Temperature (Deg C/sec)"
" TIB   = Interior Battery Temperature (Deg C)"
" CTHIB = Battery Interior Capacitance (Watt-Sec / Deg C) "
" HINB  = Input Heating Power (Watts) "
HINB = PWLC1+PWLC2+PWLC3+PWLC4+PWLC5+PWLC6+PWLC7+PWLC8+PWLC9+PWLC10
" HSB   = Interor-Surface Conduction Heat Transfer (Watts) "
" TSB   = Battery Surface Temperature (deg C) "
" RSB   = Interior-Surface Conduction H-T Coefficient(deg C/Watts)"
HSB      = (TIB-TSB)/RSB
TIBS     = (1.0/CTHIB)*(HINB-HSB)
TIB      = INTEG(TIBS,TIBZ)
" TSBS  = Rate of Battery Surface Temperature (deg C / sec) "
" TSB   = Battery Surface Temperature (deg C) "
" CTHS  = Battery Surface Thermal Capacitance (Watt-Sec/deg C ) "
" HOB   = Surface-to-Outside Convective Heat Transfer (Watts) "
" TOB   = Outside Air Temperature (deg C ) "
" ROB   = Surface-to-Outside Convective H-T Coefficient(deg C/Watts)"
HOB      = (TSB-TOB)/ROB
TSBS     = (1.0/CTHSB)*(HSB-HOB)
TSB      = INTEG(TSBS,TSBZ)
" DC-DC Buck Converter Model "
V1       = VGB42
" IR52  = Load Demand Current (Amperes) "
IR52     = ILOAD*STEP(TSLOAD,T)
I1S      = (1.0/L30)*(V1-V3-R3*I1)
I1       = INTEG(I1S,I1Z)
IC30     = (I1-DCYCLE*IL45-IDISCH)
VC30S    = (1.0/C30)*IC30
VC30     = INTEG(VC30S,VC30Z)
V3       = VC30+R30*IC30
IC50     = (IL45-IR52-IHKEEP-IBB14)
VC50S    = (1.0/C50)*IC50
VC50     = INTEG(VC50S, VC50Z)
V5       = VC50+R50*IC50
IL45S    = (1.0/L45)*(DCYCLE*V3-V5)
IL45     = INTEG(IL45S, IL45Z)
" Power Computations "
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" PWB14 = DC-DC Converter Power Output to 14 Volt Bus (Watts) "
PWB14    = V5*IR52
" PWLDC = DC-DC Converter Power Losses (Watts) "
PWLDC    = R3*I1**2+V3*IDISCH+V5*IHKEEP+R52*IR52**2
" PWB42 = DC-DC Converter Power Input from 42 Volt Bus (Watts) "
PWB42    = PWB14+PWLDC
" Lead Acid Battery Model "
VOCB14   = VOC6B14+VOC5B14+VOC4B14+VOC3B14+VOC2B14+VOC1B14
RICB14   = RIC6B14+RIC5B14+RIC4B14+RIC3B14+RIC2B14+RIC1B14
IBB14    = (VC50-VOCB14+R50*(IL45-IR52-IHKEEP))/(RICB14+R50)
" CFRCB14 = Cell Resistant Correction Factor "
CFRCB14  = CFRBT(TIB14)
" CSB14 = Cell capacitance within voltage limits "
CSB14    = CSB14T(IBB14)
" CSB14L= Cell capacitance outside voltage limits '
CSB14L   = CSB14LT(IBB14)
" Cell 6 "
IBC6B14  = IBB14
CSC6B14   = CELCAP(VC6B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC6B14  = CFRCB14*RIC6B14I
RLC6B14  = CFRCB14*RLC6B14I
ILC6B14  = (VOC6B14/RLC6B14)
VOC6B14, ICC6B14, VOC6B14S, PWLC6B14 = CELCOM2(IBC6B14, ILC6B14,...
                                    CSC6B14, VOC6B14Z, RIC6B14, RLC6B14)
VC6B14   = VOC6B14+RIC6B14*IBC6B14
VB6B14   = VC6B14+VB5B14
" Cell 5 "
IBC5B14  = ICC6B14
CSC5B14  = CELCAP(VC5B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC5B14  = CFRCB14*RIC5B14I
RLC5B14  = CFRCB14*RLC5B14I
ILC5B14  = (VOC5B14/RLC5B14)
VOC5B14, ICC5B14, VOC5B14S, PWLC5B14 = CELCOM2(IBC5B14, ILC5B14,...
                                    CSC5B14, VOC5B14Z, RIC5B14, RLC5B14)
VC5B14   = VOC5B14+RIC5B14*IBC5B14
VB5B14   = VC5B14+VB4B14
" Cell 4 "
IBC4B14  = ICC5B14
CSC4B14  = CELCAP(VC4B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC4B14  = CFRCB14*RIC4B14I
RLC4B14  = CFRCB14*RLC4B14I
ILC4B14  = (VOC4B14/RLC4B14)
VOC4B14, ICC4B14, VOC4B14S, PWLC4B14 = CELCOM2(IBC4B14, ILC4B14,...
                                    CSC4B14, VOC4B14Z, RIC4B14, RLC4B14)
VC4B14   = VOC4B14+RIC4B14*IBC4B14
VB4B14   = VC4B14+VB3B14
" Cell 3 "
IBC3B14  = ICC4B14
CSC3B14  = CELCAP(VC3B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC3B14  = CFRCB14*RIC3B14I
RLC3B14  = CFRCB14*RLC3B14I
ILC3B14  = (VOC3B14/RLC3B14)
VOC3B14, ICC3B14, VOC3B14S, PWLC3B14 = CELCOM2(IBC3B14, ILC3B14,...
                                    CSC3B14, VOC3B14Z, RIC3B14, RLC3B14)
VC3B14   = VOC3B14+RIC3B14*IBC3B14
VB3B14   = VC3B14+VB2B14
" Cell 2 "
IBC2B14  = ICC3B14
CSC2B14  = CELCAP(VC2B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC2B14  = CFRCB14*RIC2B14I
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RLC2B14 = CFRCB14*RLC2B14I
ILC2B14 = (VOC2B14/RLC2B14)
VOC2B14, ICC2B14, VOC2B14S, PWLC2B14 = CELCOM2(IBC2B14, ILC2B14,...
                                CSC2B14, VOC2B14Z, RIC2B14, RLC2B14)
VC2B14  = VOC2B14+RIC2B14*IBC2B14
VB2B14  = VC2B14+VB1B14
" Cell 1 "
IBC1B14 = ICC2B14
CSC1B14 = CELCAP(VC1B14, VCMNB14, VCMXB14, CSB14, CSB14L)
RIC1B14 = CFRCB14*RIC1B14I
RLC1B14 = CFRCB14*RLC1B14I
ILC1B14 = (VOC1B14/RLC1B14)
VOC1B14, ICC1B14, VOC1B14S, PWLC1B14 = CELCOM2(IBC1B14, ILC1B14,...
                                CSC1B14, VOC1B14Z, RIC1B14, RLC1B14)
VC1B14  = VOC1B14+RIC1B14*IBC1B14
VB1B14  = VC1B14
" VTB14 = Battery Terminal Voltage (Volts) "
VTB14   = VB6B14
" AHB14 = Net Battery Ampere-Hour Capacity (AH) "
AHB14S  = (1.0/3600.0)*ICC6B14
AHB14   = INTEG(AHB14S,AHB14Z)
" SOCB14= State of Charge in Coulombs "
SOCB14  = (AHB14/AHB14R)
" Power Computations "
" PWTB14= Power at the lead acid battery terminal (Watts) "
PWTB14  = VTB14*IBC6B14
" State Equations "
" TIB14S= Rate of the battery internal temperature (Deg C/Sec) "
" TIB14 = Battery internal temperature (Deg C) "
" CTHIB14= Battery internal cpacitance (Watt-sec/Deg C) "
" HINB14 = Input heating power (Watts) "
HINB14  = PWLC1B14+PWLC2B14+PWLC3B14+PWLC4B14+PWLC5B14+PWLC6B14
" HSB14 = Interior Surface Conduction Heat Transfer (Watts) "
" TSB14 = Battery Surface Temperature (Deg C) "
" RSB14 = Interior Surface Conduction H-T Coefficient(Deg C/Watts) "
HSB14   = (TIB14-TSB14)/RSB14
TIB14S  = (1.0/CTHIB14)*(HINB14-HSB14)
TIB14   = INTEG(TIB14S,TIB14Z)
" TSB14S= Rate of battery surface temperature(Deg C/Sec) "
" TSB14 = Battery surface temperature (Deg C) "
" CTHSB14= Battery surface thermal capacitance (Watt-sec/Deg C)"
" HOB14 = Surface-to-outside convective heat transfer (Watts) "
" TOB14 = Outside air temperature(Deg C) "
" ROB14 = Surface-to-outside convective H-T coefficient(Deg C/Watts)"
HOB14   = (TSB14-TOB14)/ROB14
TSB14S  = (1.0/CTHSB14)*(HSB14-HOB14)
TSB14   = INTEG(TSB14S,TSB14Z)
END DERIVATIVE
TERMT(T.GE.TFIN)
END DYNAMIC
                " Terminal Region Computations "
TERMINAL
END TERMINAL

END PROGRAM
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